APPARATUS AND METHOD FOR DETECTING NEURAL SIGNALS AND USING NEURAL SIGNALS TO DRIVE EXTERNAL FUNCTIONS

BACKGROUND

[0001] *Field of the Invention*

[0002] The present invention generally relates to an apparatus for detecting neural activity and, more specifically, for detecting neural activity for the purpose of control of an external device.

[0003] *Description of the Related Art*

[0004] Muscle paralysis affects over one hundred thousand people in the United States and approximately one million people worldwide. One approach used to provide assistance to paralyzed people has been described by the U.S. Patent No. 4,852,573, which is hereby incorporated by reference.

[0005] One class of patients who face severe difficulties in their daily lives is those with locked-in syndrome. Locked-in syndrome patients generally have a cognitively intact brain and a completely paralyzed body. They are alert but cannot move or talk. They face a life-long challenge to communicate. Some patients may use eye movements, blinks or remnants of muscle movements to indicate binary signals, such as "yes" or "no." To enhance communication

with these patients, several devices have been developed including electroencephalographic (EEG) control of a computer. These systems can provide patients with the ability to spell words.

[0006] One approach is to implant the neocortex using a neurotrophic electrode that uses trophic factors to encourage growth of neural tissue into a hollow electrode tip that contains two wires. The neural tissue is held firmly within the tip because it grows through both ends and joins with neighboring neuropil. This has provided stable long-term recordings in rats and monkeys for up to sixteen months. The histological analysis in rats and monkeys shows normal neuropil without neurons but with an abundance of myelinated axons. Similar implantation on human patients have shown that stable brain signals can be recorded and the patients can control these signals and to use them to drive a cursor on a computer screen.

[0007] The above approach requires an intrusive insertion of neurotrophic electrodes inside of the cortex, which requires risky and delicate surgery. Thus, there is a need for a system and method that enable capturing of neural signals without an extensive and intrusive insertion of neurotrophic electrodes.

SUMMARY OF THE INVENTION

[0008] The present invention, in one aspect, is an apparatus for detecting neural signals emanating from inside a brain within a cranium that is covered by a scalp and for transmitting the signals to an external receiver. A first conductive skull screw, capable of being implanted in the cranium and under the scalp, has a predefined length that is at least as long as the thickness of

the cranium, but less than a thickness that would cause the first conductive screw to invade the brain. A second conductive skull screw, capable of being implanted in the cranium and under the scalp, has a predefined length that is at least as long as the thickness of the cranium, but less than a thickness that would cause the second conductive screw to invade the brain. A transponder is electrically coupled to the first conductive skull screw and to the second conductive skull screw. The transponder is capable of being implanted between the cranium and the scalp. The transponder is also capable of detecting a differential electrical potential between the first conductive skull screw and the second conductive skull screw and generating a signal representative thereof. The transponder is also capable of transmitting the signal to the external receiver.

[0009] In another aspect, the invention is an apparatus for detecting neural signals emanating from inside a brain within a cranium that is covered by a scalp and for transmitting the signals to a processing device. A first surface electrode is placed on the scalp above the first conductive skull screw. A second surface electrode is placed on the scalp above the second conductive skull screw. An amplifier is electrically coupled to the first surface electrode and to the second surface electrode. The amplifier is capable of detecting a differential potential between the first surface electrode and the second surface electrode, thereby generating a signal representative thereof. The amplifier is also capable of transmitting the signal to the processing device.

[0010] In another aspect, the invention is a method for communicating a neural signal inside a brain to a remote receiver. A first conductive skull screw is inserted in a cranium under a scalp in a first location. A second conductive skull screw is inserted in a cranium under the scalp in a

second location. The first location and the second location are chosen so that a change in neural electrical potential between the first conductive skull screw and the second conductive skull screw occurs when a patient performs a neural task. A transponder is implanted under the scalp. The transponder is electrically coupled to the first conductive skull screw and to the second conductive skull screw. The change in neural electrical potential between the first conductive skull screw and the second conductive skull screw is detected. A signal representative of the change in neural electrical potential is transmitted from the transponder to the remote receiver.

[0011] In yet another aspect, the invention is a method for communicating a neural signal inside a brain of a patient to a remote receiver. A first conductive skull screw is inserted in a cranium under a scalp in a first location adjacent to a first location. A second conductive skull screw is inserted in a cranium under the scalp in a second location. The first location and the second location are chosen so that a change in neural electrical potential between the first conductive skull screw and the second conductive skull screw occurs when a patient performs a neural task. A first surface electrode is placed on the scalp and above the first conductive skull screw. A second surface electrode is placed on the scalp and above the second conductive skull screw. The first surface electrode and the second surface electrode are electrically coupled to an amplifier. A differential electrical potential is detected between the first surface electrode and the second surface electrode. The differential electrical potential represents the neural signal. A signal corresponding to the differential electrical potential is transferred to a signal processor.

[0012] These and other aspects of the invention will become apparent from the following description of the preferred embodiments taken in conjunction with the following drawings. As

would be obvious to one skilled in the art, many variations and modifications of the invention may be effected without departing from the spirit and scope of the novel concepts of the disclosure.

BRIEF DESCRIPTION OF THE FIGURES OF THE DRAWINGS

[0013] **FIG. 1** is a cutaway view of an electrode implantation according to the invention.

[0014] **FIG. 2** illustrates an alternative embodiment of a connector connecting an electrode and the amplifier.

[0015] **FIG. 3** is a flow chart of a process for identifying received neural signals.

[0016] **FIG. 4** illustrates working of a power induction circuit.

[0017] **FIG. 5** is a cutaway view of an alternative embodiment of the invention.

DETAILED DESCRIPTION

[0018] A preferred embodiment of the invention is now described in detail. Referring to the drawings, like numbers indicate like parts throughout the views. As used in the description herein and throughout the claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise: the meaning of "a," "an," and "the" includes plural reference, the meaning of "in" includes "in" and "on."

[0019] The invention provides a less invasive and easier to implement brain-computer interface device and method. The method includes implantation of conductive skull screws in the skull of a patient and adjacent to the outer layers of the patient's cortex. The device receives signals from the cortex and transmits them to a nearby receiver where they are processed to drive a cursor on a computer or other electronic devices. For people suffering from "locked-in" syndrome, cortical control of the external environment can restore a means of communication via computer cursor control. Cortical control signals allow control of various assistive technology devices such as wheelchairs, or may even restore control of a paralyzed limb. These cortical signals can consist of either fast transients (FTs, such as action potentials) or local field potentials (LFPs). With training, some patients have been able to use LFPs or FTs to control virtual tools such as a keyboard cursor and a computer-simulated digit (cyber digit).

[0020] As shown in FIG. 1, one embodiment of the invention **100** includes a first conductive skull screw **102** and a second conductive skull screw **104** that are implanted in the cranium **114** of a patient. The skull screws **102** and **104**, are typically made of stainless steel and each have a length corresponding at least to the thickness of the cranium **114**, but are not long enough to invade the patient's brain **116** when implanted. The first skull screw **102** is placed at a first location and the second skull screw **104** is placed at a second location. The first location and the second location are chosen so that a change in neural electrical potential between the first conductive skull screw and the second conductive skull screw occurs when a patient performs a neural task. For example, if the patient generates a thought that would cause movement in an average individual, a localized neural electrical potential will be generated. This electrical

potential is sensed in the patient and the first skull screw **102** may be implanted at the site of the localized neural electrical potential. The second skull screw **104** is then placed at a location near a region of the patient's cortex where the localized neural electrical potential is not sensed and, thus, serves as a reference electrode. The location may be determined through performance a functional magnetic resonance imaging (fMRI) process of the cortex.

[0021] The conductive skull screws **102** and **104** should be electrically conductive and corrosion resistant. They can be metallic screws made from stainless steel or other suitable conductive materials, such a conductive ceramic or non-metallic material. The dimensions for the conductive skull screws **102** and **104**, which act like electrodes, are typically between 1/16 inches to ½ inches in diameter and ¼ inches to 1 and ½ inches in length. Generally, the conductive skull screws **102** and **104**, after implantation, are fixed in the skull without going into the brain.

[0022] A sufficient electrical potential that is measured between the first skull screw **102** and the second skull screw **104** forms a neural signal that indicates a desire on behalf of the patient for a predetermined action to take place.

[0023] The first conductive skull screw **102** and a second conductive skull screw **104** are connected via wires **106** to a transponder **101**, which includes amplifier **108**, a transmitter **110** and a power induction circuit **112**. The amplifier **108** amplifies the neural signal sensed between the skull screws **102** and **104**. The wires **106** are made from a conductive material and are insulated to prevent electrical contact with the body other than in selected areas. After

amplification, the neural signal is transmitted via the wireless transmitter **110** to a remote receiver **122** that is connected to a computer **120**.

[0024] The power induction circuit 112 powers the amplifier 108 and the transmitter 110. The power induction circuit **112** is responsive to an electromagnetic signal and generates electricity therefrom, thereby being capable of supplying power to the amplifier **108** and the transmitter **110** without requiring a battery. The amplifier **108**, the transmitter **110**, and the power induction circuit **112** may also be built into a single unit that is suitable for implantation. The conductive skull screws **102** and **104**, the wires **106**, the amplifier **108**, the transmitter **110**, and the induction circuit **112** may be minimized in size, sterilized, and implanted under the scalp **124**, thereby avoiding entry of pathogenic organisms.

[0025] In one illustrative embodiment, the amplifier **108** provides a gain of about 1,000 to the voltage differential sensed between the conductive skull screws **102** and **104**. The amplified signal that represents the voltage differential is then passed to the transmitter **110**. The amplifier **108** may also be capable of noise reduction.

[0026] In one embodiment, the transmitter **110** is a frequency modulated (FM) transmitter. However, as is readily apparent to those of skill in the art, there are many other types of suitable transmitters, including AM.

[0027] In one embodiment, the transmitter **110** can also be a very high frequency ("VHF") FM unit employing a modulated subcarrier. This approach permits adequate range and

frequency response as well as freedom from artifacts. Power consumption can be minimized (and thus useful life extended) by using low power transistors and low-drain circuitry. In addition, using a switching arrangement such as a magnetic reed switch, which applies power only when needed, can further reduce power consumption.

[0028] Since the transmitter **110**, the amplifier **108**, and the power induction circuit **112** are implanted in living tissue, special encapsulation procedures are required both to ensure biocompatibility and to prevent the infusion of body fluids into the circuitry, which could cause a malfunction. A suitable encapsulating material is used, such as one of the many types of polymer that have been approved for implantation. The transmitter **110** is then coated with tissue-compatible silastic or other suitable material and then sterilized. The permeable silastic will allow sterilization of the entire unit, while protecting the sealant against mechanical abrasion, which could expose an unsterilized subsurface.

[0029] Typically, the differential potential between the conductive skull screws **102** and **104** has a duration between 10 milliseconds to a few hundred milliseconds during a neural activity event.

[0030] To facilitate connection, as shown in FIG. 2, each wire **106** may be divided into two separated sections and joined by a connector **200**. The connector **200** includes a male plug **202** and a complimentary female plug **204**.

[0031] FIG. 3 illustrates a process **300** for determining if a received signal is a valid indication of neural activity. The signal is recognized as a valid signal if it has a voltage greater than a predetermined level and if its duration is longer than a predetermined period. The process **300** checks if a signal is received, step **302**. If no signal has been received, the computing device **120** continues monitor the receiver **122**.

[0032] After a signal is received, the computer device **120** checks whether the signal has a voltage greater than the predetermined level, step **304**. If the signal is not sufficiently strong, it is ignored and the computing device **120** continues to monitor the receiver **122**. If the signal is sufficiently strong, the computing device **120** counts the duration of the signal, step **306**. After counting the duration, the duration is compared with a predetermined duration, step **308**. If the duration is longer than the predetermined duration, the signal is marked as a good signal, step **310**. The computer **120** may then take a predetermined action. If the duration is shorter than the predefined duration, the signal is ignored. By comparing the recovered signal with the predefined threshold voltage level and the predefined duration, spurious signals can be eliminated.

[0033] The inductive power supply **400** is shown in FIG. 4. The power induction circuit **112** is energized by electromagnetic radiation produced by an inductor **402** connected to a power source **404**. The power source **404** may be powered by an external power supply, a battery, or other suitable sources. The power induction circuit **112** is exposed to the electromagnetic radiation and produces an electrical current to power the transponder **101**. In an alternative embodiment, the transponder **101** may be directly connected to a power supply.

In another embodiment, as shown in FIG. 5, the conductive skull screws **102** and **104** are implanted in the cranium **114** and under the scalp **124**. Two surface electrodes **504** and **506** are placed on the top of the conductive skull screws **102** and **104** above the scalp **124**. The surface electrodes **504** and **506** are connected to an amplifier **508**, which may be connected directly to a computational device **520** or may be connected to a transmitter, as described above. The surface electrodes are secured to the scalp **124** using adhesives or other methods known to those skilled in the art. In this embodiment, the placement of the screws in the patient's skull provides a mechanism to improve transfer of neural signals through the skull, thereby improving signal reception during such diagnostic procedures, such electroencephalography (EEG).

[0034] Before the implantation of the conductive skull screws **102** and **104** a pre-operative assessment of the patient is conducted. The pre-operative assessment consists of assessing cognition using questions requiring a "yes" or "no" answer and acquiring knowledge of pre-morbid cognitive baseline, including the education level. After the assessment, a functional MRI (fMRI) is performed to determine if, where and when, neural activity exists. During the fMRI process, a patient is encouraged to visualize a performance of a specific movement. During the fMRI, a clinician records the region of the cortex where a neural signal occurs and this region is then associated with that specific movement.

[0035] The fMRI results guide implantation site selection. Two sites are selected: one for the active conductive skull screw and one for the neutral conductive skull screw. A craniotomy

is performed over the target areas identified at surgery. Alignment with the active areas noted on the pre-operative fMRI.

[0036] After implantation, the invention is capable of detecting differential potentials in the order of few hundred microvolts between the conductive skull screws **102** and **104**. The differential potential detected may have different frequencies, such as 5 Hz, 10 Hz, 20 Hz, 40 Hz, etc.

[0037] In view of the method being executable on a computing device, the present invention includes programs resident in a computer readable medium, where the programs direct a server or other computer device having a computer platform to perform the steps of the method. The computer readable medium can be the memory of the server, or can be in a connective database. Further, the computer readable medium can be in a secondary storage media that is loadable onto a wireless communications device computer platform, such as a magnetic disk or tape, optical disk, hard disk, flash memory, or other storage media as is known in the art.

[0038] While the invention has been particularly shown and described with reference to a embodiment shown herein, it will be understood by those skilled in the art that various changes in form and detail maybe made without departing from the spirit and scope of the present invention as set for the in the following claims. Furthermore, although elements of the invention may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.